Chapter 9
General Construction Considerations

9-1. General

The design of an earth or rock-fill dam is a process continued until construction is completed. Much additional information on the characteristics of foundations and abutments is obtained during clearing, stripping, and trenching operations, which may confirm or contradict design assumptions based on earlier geologic studies and subsurface exploration by drill holes and test pits. Operations in the borrow areas and in required excavations also provide much data pertinent to characteristics of fill material and of excavated slopes. Weather and groundwater conditions during construction may significantly alter water contents of proposed fill material, or create seepage and/or hydraulic conditions, necessitating modifications in design. Projects must be continuously evaluated and "re-engineered," as required, during construction, to ensure that the final design is compatible with conditions encountered during construction. Design and design review personnel will make construction site visits to determine whether design modifications are required to meet actual field conditions (see ER 1110-2-112). Environmental considerations discussed in paragraph 2-5 must be given attention in construction operations.

9-2. Obtaining Quality Construction

a. Definitions (ER 1180-1-6).

(1) Quality is conformance to properly developed requirements. In the case of construction contracts, these requirements are established by the contract specifications and drawings.

(2) Quality management is all control and assurance activities instituted to achieve the product quality established by the contract requirements.

(3) Contractor quality control (CQC) is the construction contractor's system to manage, control, and document his own, his supplier's, and his subcontractor's activities to comply with contract requirements.[1]

(4) Quality assurance (QA) is the procedure by which the Government fulfills its responsibility to be certain the CQC is functioning and the specified end product is realized.

b. Policy. Obtaining quality construction is a combined responsibility of the construction contractor and the Government. The contract documents establish the level of quality required in the project to be constructed. In contracts of $1 million or greater, detailed CQC will be applied and a special CQC Section will be included in the contract. CEGS-01440 is to be used in preparation of the CQC Section. QA is required on all construction contracts. The extent of assurance is commensurate with the value and complexity of the contracts involved. QA testing is required (ER 1180-1-6).

c. Contractor responsibility. Contractors shall be responsible for all activities necessary to manage, control, and document work so as to ensure compliance with the contract P&S. The contractor's responsibility includes ensuring adequate quality control services are provided for work accomplished by his organization, suppliers, subcontractors, technical laboratories, and consultants. For contracts of $1 million or greater, contractors will be required to prepare a quality control plan (ER 1180-1-6).

d. Government responsibility. QA is the process by which the Government ensures end product quality. This process starts well before construction and includes reviews of the P&S for biddability and constructibility, plan-in-hand site reviews, coordination with using agencies or local interests, establishment of performance periods and quality control requirements, field office planning, preparation of QA plans, reviews of quality control plans, enforcement of contract clauses, and acceptance of completed construction (ER 1180-1-6).

e. QA for procedural specifications. Some QA testing in the case of earthwork embankment and concrete dam structures must be conducted continuously. A comprehensive QA testing program by the Government is necessary when specifications limit the contractor to prescriptive procedures leaving the responsibility for end product quality to the Government (ER 1180-1-6).

9-3. Stage Construction

a. The term "stage construction" is limited here to construction of an embankment over a period of time with substantial intervals between stages, during which little or

[1] Additional information is given in EP 715-1-2 and International Commission on Large Dams Bulletin 56 "Quality Control for Fill Dams" (International Commission on Large Dams 1986).

no fill is placed. Where a foundation is weak and compressible, or where impervious fill is on the wet side of normally acceptable placement water contents, it may be desirable to restrict the rate of fill placement or to cease fill placement for periods of time to permit excess pore-water pressures in the foundation and/or the fill to dissipate. Another beneficial effect of periods of inactivity is that rates of pore-pressure buildup in partially saturated soils upon resumption to fill placement may be reduced (see Clough and Snyder (1966) and Plate VIII-3 of EM 1110-2-1902).

b. High embankments. Where high embankments are constructed in narrow valleys, it may be possible to place fill rapidly, which will increase pore-pressure buildup in the embankment and/or foundation. Rather than reduce the rate of fill placement unduly, it may be desirable to use flatter slopes, add stabilizing berms, or build the embankment in stages.

9-4. Stream Diversion

a. Requirements. Requirements for diversion of streamflow during construction and the relative ease and cost of stream control measures may govern site selection. Since river diversion is a critical operation in constructing a dam, the method and time schedules for diversion are important elements of design.

b. Methods of stream control.

(1) The principal factors that determine methods of stream control are the hydrology of the stream, the topography and geology of the site, and the construction schedule. A common diversion method is to construct the permanent outlet works and a portion of the embankment adjacent to an abutment in the initial construction period. During the next construction period, at a time when flood possibility is low and favorable embankment placement conditions are likely, a cofferdam is constructed to divert riverflow through the outlet works (guidance on planning, design, and construction of cofferdams is given in ER 1110-2-2901 and EM 1110-2-2503). A downstream cofferdam may also be required until the embankment has been completed above tailwater elevation. In the period following diversion, the closure section is first brought up to a level with the remainder of the dam, after which the embankment is completed to a given height as rapidly as possible in preparation for high water. In the final period, the entire dam is brought up to full height. Simultaneous closure of upstream and downstream cofferdams may facilitate a difficult closure. The downstream cofferdam puts a back head on the construction area and reduces erosion of the downstream slope and adjacent foundation.

(2) Cofferdams are often constructed in two stages: first, a small diversion cofferdam is constructed upstream of the main embankment, and second, the main cofferdam is constructed. The cofferdam may form a permanent part of the embankment wherever suitable strength and permeability characteristics of the fill can be obtained. Gravel fill is particularly suitable for cofferdam construction since it readily compacts under water. If seepage considerations require an upstream impervious blanket on a cofferdam built of pervious soil, the blanket should be removed later if it restricts drainage during drawdown.

c. Cofferdam design. Major cofferdams are those cellular or embankment cofferdams, which, upon failure, would cause major damage downstream and/or considerable damage to the permanent work. Minor cofferdams are those which would result in only minor flooding of the construction work. All major cofferdams should be planned, designed, and constructed to the same level of engineering competency as for main dams. Design considerations should include minimum required top elevation, hydrologic records, hydrographic and topographic information, subsurface exploration, slope protection, seepage control, stability and settlement analyses, and sources of construction materials. The rate of construction and fill placement must be such to prevent overtopping during initial closure of the cofferdam. The cofferdam for Cerrillos Dam, Puerto Rico, was unique in that it was designed to handle being overtopped. The overtopping protection consisted of anchoring welded steel rebar/wire mesh to the downstream face. Crest protection was provided by gabions with asphalt paving (U.S. Army Engineer District, Jacksonville 1983). Minor cofferdams can be the responsibility of the contractor. Excavations for permanent structures should be made so as not to undermine the cofferdam foundation or otherwise lead to instability. Adequate space should be provided between the cofferdam and structural excavation to accommodate remedial work such as berms, toe buttresses, and foundation anchors should they be necessary.

d. Protection of embankment.

(1) Where hydrologic conditions require, emergency outlets should be provided to avoid possible overtopping of the incomplete embankment by floods that exceed the capacity of the outlet works. As the dam is raised, the probability of overtopping gradually decreases as a result of increased discharge capacity and reservoir storage.

Should overtopping occur, however, damage to the partially completed structure and to downstream property increases with increased embankment heights. It is prudent to provide emergency outlets by leaving gaps or low areas in the concrete spillway or gate structure, or in the embankment during wintering over periods. Excavation of portions of the spillway approach and discharge channels, combined with maintaining low concrete weir sections, may provide protection for the later phases of embankment construction during which the potential damage is greatest.

(2) When a portion of the embankment is constructed before diversion of the river, temporary riprap or other erosion protection may be required for the toe of the embankment adjacent to the channel. This temporary protection must be removed before placement of fill for the closure section.

(3) In some cases the cost of providing sufficient flow capacity to avoid overtopping becomes excessive, and it is more appropriate to provide protection for possible overflow during high water conditions, as was done at Blakely Mountain Dam (U.S. Army Engineer Waterways Experiment Station 1956).

(4) Within the past 10 years innovative methods for providing overtopping protection of embankments have been developed. These include roller-compacted concrete and articulated concrete blocks tied together by cables and anchored in place (see Hansen 1992; Powledge, Rhone, and Clopper 1991; Wooten, Powledge, and Whiteside 1992; and Powledge and Pravdivets 1992).

9-5. Closure Section

a. Introduction. Because closure sections of earth dams are usually short in length and are rapidly brought to grade, two problems are inherent in their construction. First, the development of high excess porewater pressures in the foundation and/or embankment is accentuated, and second, transverse cracks may develop at the juncture of the closure section with the adjacent already constructed embankment as a result of differential settlement. When the construction schedule permits, excess porewater pressures in the embankment may be minimized by providing inclined drainage layers adjacent to the impervious core and by placing gently sloping drainage layers at vertical intervals within semi-impervious random zones. However, acceleration of foundation consolidation by means of sand blankets and vertical wick drains or reduction of embankment pore pressures by stage construction is generally impracticable in a closure section. A more suitable procedure is to use flatter slopes or stabilizing berms. Cracking because of differential settlement may be minimized by making the end slopes of previously completed embankment sections no steeper than 1 vertical on 4 horizontal. The soil on the end slopes of previously completed embankment sections should be cut back to well-compacted material that has not been affected by wetting, drying, or frost action. It may be desirable to place core material at higher water contents than elsewhere to ensure a more plastic material which can adjust without cracking, but the closure section design must then consider the effects of increased porewater pressures within the fill. The stability of temporary end slopes of embankment sections should be checked.

b. Limit. If specifications limit the rate of fill placement, piezometers must be installed with tips in the foundation and in the embankment to monitor porewater pressures. Conduits should not be built in closure sections or near enough to closure sections to be influenced by the induced loads.

c. Closure section. Closure sections, with foundation cutoff trenches if required, are generally constructed in the dry, behind diversion cofferdams. In a few cases, the lower portions of rock-fill closure sections with "impervious" zones of cohesionless sands and gravels have been successfully constructed under water (see Pope 1960). Hydraulic aspects of river diversion and closures are presented in EM 1110-2-1602.

9-6. Construction/Design Interface

It is essential that all of the construction personnel associated with an earth or rock-fill dam be familiar with the design criteria, performance requirements, and any special details of the project. As discussed in paragraph 4-7, coordination between design and construction is accomplished through the report on engineering considerations and instructions to field personnel, preconstruction orientation for construction engineers by the designers, and required visits to the site by the designers.

9-7. Visual Observations

Visual observations during all phases of construction provide one of the most useful means for controlling construction and assessing validity of design assumptions. It is not practical, for economic reasons, to perform enough field density control tests, to install enough instrumentation, and to obtain enough data from preconstruction subsurface explorations to ensure that all troublesome conditions are detected and that satisfactory construction is being achieved. While test data and instrument observations provide more detailed and quantitative information than visual observations, they serve principally to strengthen and supplement visual observations of the embankment and foundation as the various construction activities are going on. Field forces should be constantly on the alert for conditions not anticipated in the design, such as excessively soft areas in the foundation; jointing, faulting, and fracturing in rock foundations; unusual seepage; bulging and slumping of embankment slopes; excavation movements; cracks in slopes; and the like. It is particularly important to make observations during the first filling of the reservoir as weaknesses in a completed dam often show up at this time. For this reason, each reservoir project is required to have an "Initial Filling Plan" (discussed in paragraph 9-8). Visual observations of possible distress such as cracking, the appearance of turbid water in downstream toe drainage systems, erosion of riprap, soft wet spots downstream of the abutments or at the downstream toe or on the downstream slope, and other observations are important. Observations of instrumentation also yield valuable data in this respect.

9-8. Compaction Control

a. Principal compaction. Principal compaction control is achieved by enforcement of specifications relating to placement water content, lift thickness, compacting equipment, and number of passes for the various types of fill being placed. Experienced inspectors can quickly learn to distinguish visually whether the various contents are within the specified range for compaction, and to assess whether satisfactory compaction is being achieved. This ability is gained by closely observing the behavior of the materials during spreading and compacting operations.

b. Field compaction. A systematic program of field compaction control should be established and executed, involving determinations of in-place densities and water contents, and relating the results to specified or desired limits of densities and water contents. Special emphasis must be placed in the compaction program on the need to obtain sufficient densities in each lift along the impervious core contact area on the abutments, and in each lift on either side of the outlet conduit along the backfill-conduit contact to verify adequate compaction in these and other critical zones. If good correlations can be obtained between direct methods and nuclear moisture-density meters, the latter may be used to increase the number of determinations with a minimum increase in time and effort, but nuclear measurements cannot be used to replace direct determinations. A more reliable method for determination of field water content is available using the microwave oven (see below).

c. Oven system. A computer-controlled microwave oven system (CCMOS) is useful for rapid determination of water content for compaction control. The principle of operation of the system is that water content specimens are weighed continuously while being heated by microwave energy, and a computer monitors change in water content with time and terminates drying when all free water has been removed. A water content test in the CCMOS requires 10 to 15 min, and the system has been field tested at Yatesville Lake and Gallipolis Lock projects. Test results indicated that CCMOS produces water contents within 0.5 percent of conventional oven water content. Special procedures must be used when drying materials which burst from internal steam pressure during microwave drying (which includes some gravel particles and shales) and highly organic material, which requires a special drying cycle. Gypsum-rich soils are dehydrated by the microwave oven system giving erroneous results and should not be analyzed by this method. However, it should be noted that a special drying procedure is required to dry gypsum-rich soils in the conventional oven (Gilbert 1990, Gilbert 1991).

d. Compaction. In order to check the adequacy of compaction in the various embankment zones and to confirm the validity of the design shear strengths and other engineering parameters, a systematic schedule for obtaining 1-cu-ft test pit samples at various elevations and locations in the embankment should be established. Samples so obtained will be suitably packed and shipped to division laboratories for performance of appropriate tests.

9-9. Initial Reservoir Filling

a. General. The initial reservoir filling is defined as a deliberate impoundment to meet project purposes and is a continuing process as successively higher pools are attained for flood control projects. The initial reservoir filling is the first test of the dam to perform the function for which it was designed. In order to monitor this performance, the rate of filling should be controlled to the extent feasible, to allow as much time as needed for a predetermined surveillance program including the observation and analysis of instrumentation data (Duscha and Jansen 1988). A design memorandum (DM) on initial reservoir filling is required for all new reservoir projects.[1]

[1] Additional information is given in ETL 1110-2-231.

b. Design memorandum. As a minimum, the DM on initial reservoir filling will include the following (EM 1110-2-3600):

(1) Reservoir regulations during project construction stage(s).

(2) Water control plan.

(3) Project surveillance.

(4) Cultural site surveillance.

(5) Flood emergency plan.

(6) Public affairs.

(7) Safety plan.

(8) Transportation and communications.

9-10. Construction Records and Reports

a. General. Engineering data relating to project structures will be collected and permanently retained at the project site (see Appendix A of ER 1110-2-100). This information has many uses such as determining the validity of claims made by construction contractors, designing future alterations and additions to the structure, familiarizing new personnel with the project, and providing guidance for designing comparable future projects. These documents will include as many detailed photographs as necessary. This information provides the basis for analysis and remedial action in the event of future distress.

b. Field control data. Records including field control data on methods of compaction, in-place unit weight and moisture content, piezometers, surface monuments, and inclinometers are kept for use in construction, operation, and maintenance of the project. Instructions regarding specific forms to use for field data control are given in ER 1110-2-1925.

c. As-constructed drawings. As construction of a project progresses, plans will be prepared showing the work as actually constructed. Changes may be indicated in ink on prints of the construction drawings or the tracings may be revised and new prints made to show the work as constructed, as specified in ER 1110-2-1200.

d. Embankment criteria and foundation report. Earth and earth-rock-fill dams require an embankment criteria and foundation report to provide a summary of significant design assumptions and computations, specification requirements, construction procedures, field control and record control test data, and embankment performance as monitored by instrumentation during construction and during initial reservoir filling. This report is usually written by persons with first-hand knowledge of the project design and construction. The written text is brief with the main presentation consisting of a set of identified construction photographs, data summary tables, and as-constructed drawings. This report provides in one volume the significant information needed by engineers to familiarize themselves with the project and to re-evaluate the embankment in the event unsatisfactory performance occurs (see ER 1110-2-1901).

e. Construction foundation report. In addition to an embankment criteria and foundation report, all major and unique dams require a construction foundation report to be completed within 6 months after completion of the project or part of the project for which the report is written (see Appendix A of ER 1110-1-1801 for a suggested outline for foundation reports). This report documents observations of subsurface conditions encountered in all excavations and provides the most complete record of subsurface conditions and treatment of the foundation. The foundation report should be complete with such details as dip and strike of rock, faults, artisan conditions, and other characteristics of foundation materials. A complete history of the project in narrative form should be written, giving the schedule of starting and completing the various phases of the work, describing construction methods and equipment, summarizing quantities of materials involved, and other pertinent data. An accurate record should be maintained as to the extent and removal of all temporary riprap or stockpiled rock such as that used for diversion channel protection. The construction foundation report saves valuable time by eliminating the need to search through voluminous construction records of the dam to find needed information to use in planning remedial action should failure or partial failure of a structure occur as a result of foundation deficiencies.

f. Photographs and video tape taken during construction. Embankment criteria and foundation and construction foundation reports should be supplemented by photographs that clearly depict conditions existing during embankment and foundation construction. Routine photographs should be taken at regular intervals, and additional pictures should be taken of items of specific interest, such as the preparation of foundations and dam abutments. For these items, color photographs should be taken. The captions of all photographs should contain the name of the project, the date on which the photograph was taken, the identity of the feature being photographed, and the location of the camera. In reports containing a number of photographs, an alternative would be an index map with a circle indicating the location of the camera with an arrow pointing in the direction the camera was pointing, with each location keyed to the numbers on the accompanying photographs (EM 1110-2-1911). Consideration should be given to using video tape where possible to document construction of the dam.